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Moisture Equilibria of Dehydrated Mashed Potato Flakes

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SUMMARY

With many dehydrated foods, the moisture content for optimum stability can be calculated from equilibrium moisture data by means of the Brunauer, Emmett, and Teller (B.E.T.) theory of multimolecular adsorption. The moisture content corresponding to the B.E.T. monolayer agrees closely with the moisture content for optimum stability. No data have been published on the moisture sorption properties of potato flakes, a relatively new form of dehydrated mashed potatoes.

Moisture sorption studies were made on flakes made from 8 potato varieties ranging in specific gravity from 1.066 to 1.904. Regardless of variety or geographical origin, the flakes had similar moisture sorption properties and should exhibit similar storage stability. According to the B.E.T. equation, the flakes should have an optimum storage value between 5.1 and 5.8% moisture; this value agrees with data obtained from storage tests.

INTRODUCTION

Moisture sorption data of foodstuffs have been used mainly for selecting packaging materials or establishing allowable humidity limits during storage and packaging. Salwin (1959) showed that these data may be used to calculate the optimum moisture level for maximum stability against oxidative deterioration. Optimum moisture levels had already been shown experimentally for walnuts (Rockland, 1957) and dry whole milk (Roger, 1935). Furthermore, Burton (1945, 1949) had showed that overdrying of potato granules is conducive to oxidative rancidity.

Salwin (1959) found that the moisture content at which certain dehydrated foods have good storage stability agreed closely with the moisture content representing a calculated monomolecular layer of adsorbed water. This monomolecular layer can be calculated from moisture sorption data by means of the Brunauer, Emmett, and Teller (B.E.T.) theory of multimolecular adsorption (Brunauer *et al.*, 1938). This layer can be regarded as a film that protects the food particles from attack by oxygen.

Potato flakes, a relatively new dehydrated food product, have found ready consumer acceptance and achieved considerable commercial importance during the last three years. Knowledge of their moisture sorption properties can help manufacturers extend the shelf life of the product. Though moisture sorption studies have been made on potato starch (Hellman and Melvin, 1950) and other potato products (Makower and Dehority, 1943; Gane, 1950), no moisture sorption data on potato flakes have been published.

In the potato flake process, precooking (Cording *et al.*, 1955) and cooling (Cording *et al.*, 1959) steps prior to final cooking and drying improve the texture of the product. The reason is probably the modification of the starch within the potato cells. These in-process modifications and the use of monoglycerides (Anonymous, 1959) as texture improvers have extended the process to many potato varieties. The modifications and the many varieties used raised the question whether there would be any differences in the moisture sorption properties of the various flakes. Hence, moisture sorption data were obtained on flakes representative of the wide geographical distribution of flake plants. In sum, the study was made: 1) to observe the effects of processing and raw material differences (specific gravity and geographical origin) on the moisture sorption capacity of the various flakes, and 2) to calculate for each variety studied the optimum moisture content and to compare these values with available storage data.

MATERIALS AND METHODS

The equilibrium moisture data were obtained by exposing flakes to atmospheres of different relative humidities until the corresponding equilibrium moisture contents were reached. These atmospheres, ranging in relative humidity from 12.0 to 75.8% at 77°F, were prepared by placing saturated salt solutions in the bottom section of desiccators stored at constant temperature (77°F). Table 1 lists these saturated salt solutions, their corresponding relative humidities, and appropriate literature references.

Table 1. Relative humidity of saturated salt solutions at 77°F (25°C).

Salt solution	% relative humidity	Reference
Lithium chloride	12.0	Wexler and Hasegawa (1954)
Potassium acetate	22.5	Houston and Kester (1954)
Potassium carbonate	43.7	Houston and Kester (1954)
Ammonium nitrate	63.5	O'Brien (1948)
Sodium chloride	75.8	Wexler and Hasegawa (1954)

Before exposure the flakes were ground (through 20-mesh, and retained on a 40-mesh, screen) in a Wiley mill (reference to certain products or companies does not imply an endorsement

Table 2. Equilibrium moisture content (%MFB) of flakes at 77°F at various relative humidities.

Variety and state	Spec. grav.	% relative humidity 12.0	22.5	43.7	63.5	75.8
Katahdin						
New York	1.066	4.3	5.3	7.7	12.7	18.0
Pennsylvania	1.066	4.6	5.8	7.0	12.8	17.4
White Rose						
California	1.072	4.7	5.7	7.6	12.5	17.0
Pontiac						
Minnesota	1.078	4.6	5.3	7.5	11.9	16.8
Russet						
Maine	1.078	4.7	5.5	7.6	12.7	17.1
Washington	1.084	4.8	6.4	7.4	13.5	17.6
Idaho	1.085	4.5	6.2	7.8	11.5	16.8
Cobbler						
Minnesota	1.094	4.8	5.7	7.8	12.4	16.7
Av.		4.6	5.7	7.5	12.5	17.2

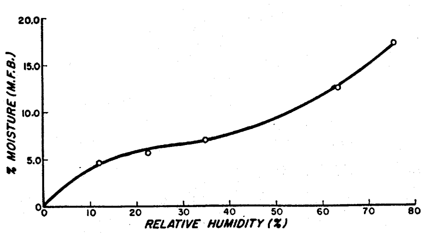

Fig. 1. Moisture sorption of dehydrated mashed potato flakes (77°F).

over others not mentioned). Samples for moisture analysis were taken, and, for each variety, weighed samples in tared analytical weighing bottles were placed in the desiccators to equilibrate. The weight of each sample was checked periodically, the amount of moisture change was noted, and the moisture content at that time was calculated. For most of the samples, equilibrium was reached in four days. All the data reported were obtained by this technique. The flakes were all prepared as described by Cording *et al.*, (1957) and ranged in moisture content from 5.0 to 5.3% MFB. Moisture content was determined by Brabender as reported by Cording *et al.* (1957). Organoleptic testing was as follows: Samples were reconstituted as described earlier (Cording *et al.*, 1961), and the taste panel, consisting of 18 trained tasters, judged the acceptability of the flakes being tested.

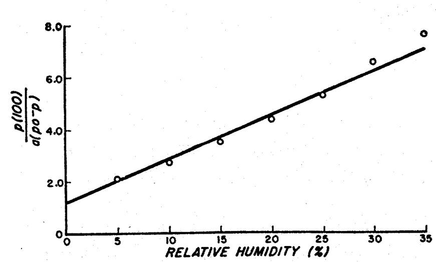

Fig. 2. B.E.T. plot for mashed potato flakes.

Taste-panel evaluation also included a simple ranking test; differences between samples were calculated at the 95% level of reliability.

RESULTS AND DISCUSSION

Effect of varietal and processing differences. Equilibrium moisture data were obtained for eight potato varieties. These varieties ranged in specific gravity from 1.066 to 1.094 and represent a good cross section of the potato flake industry. The varieties and their corresponding moisture sorption data are presented in Table 2; all these flakes were made in the same way, i.e., processing included both the precooking and cooling steps. The data in Table 2 reveal the great similarity in equilibrium moisture isotherms; the respective equilibrium moisture contents corresponding to each relative humidity are fairly close. For instance, the moisture contents corresponding to 63.5% relative humidity range from 11.9 to 13.5%; this is the widest range of values. Accordingly, the shapes of the isotherms are identical. Rather than plot all the points, the moisture contents were averaged for the eight varieties and these are plotted in Fig. 1; these values are also included in Table 2. The sigmoid shape is very similar to that of the isotherms of potato starch and other potato products; however, the moisture values for the same relative humidities are higher for starch than for flakes.

The effect of three different processing treatments is shown in Table 3. The same lot of Washington Russets was used to produce flakes by three processing methods: 1) precooking and cooling of the slices before final cooking, 2) precooking only, and 3) no precooking or cooling before final cooking. Except for these differences, processing was identical for these three flakes. The data of Table 3 reveal only slight differences resulting from the different processing steps. Again there are no differences in the shape of the isotherms. No gross alteration in the moisture sorption capacity results from the precooking and cooling steps.

Calculation of optimum moisture content. The optimum moisture content is calculated from the equilibrium moisture data in the following way. The method consists of transforming the isotherm (in the range of 5–35% relative humidity) by the B.E.T. equation. This gives a straight line in this range, and from the slope and intercept the B.E.T. monolayer of absorbed water can be calculated.

The B.E.T. equation is:

$$\frac{p}{a(p_\circ - p)} = \frac{1}{a_1 c} + \frac{c-1}{a_1 c} \frac{p}{p_\circ}$$

In this equation, a is the grams of water per 100 g of dry matter corresponding to a relative vapor pressure, $p/p_\circ$; p is the moisture vapor pressure, and $p_\circ$ is the vapor pressure of pure water at the same temperature (77°F in this case); c is a constant related to the heat of adsorption and a_1 is the grams of water equivalent to a monomolecular layer adsorbed on 100 g of dry solids.

The data are plotted with $\frac{p(100)}{a(p_\circ - p)}$ as ordinates, and $\frac{p(100)}{p_\circ}$ (i.e., % relative humidity) as abscissae. A straight line is obtained, with slope $\frac{c-1}{a_1 c}$ and intercept $\frac{100}{a_1 c}$. From these is calculated the value of a_1, the monolayer value. This has been done for the sorption data of Table 2 and Table 3, and Table 4 gives the slope, intercept, and monolayer for each series of data.

Table 3. Effect of processing on the equilibrium moisture content (%MFB) of flakes made from Washington Russets.

Processing	% relative humidity 12.0	22.5	43.7	63.5	75.8
Precooking only	4.9	6.3	7.4	13.9	18.0
Precooking and cooling	4.8	6.4	7.4	13.5	17.6
No treatment prior to final cooking	4.9	6.3	7.2	13.6	18.5

Table 4. B.E.T. monolayer and calculated minimum moisture for optimum stability.

State and variety	Spec. grav.	From B.E.T. plot: Slope c-1 / a_1c	Intercept 100 / a_1c	% moisture: Monolayer MFB	Wet basis
Katahdin					
New York	1.066	0.172	1.30	5.4	5.1
Pennsylvania	1.066	0.180	0.90	5.3	5.0
White Rose					
California	1.072	0.160	1.35	5.8	5.4
Pontiac					
Minnesota	1.078	0.153	1.15	6.1	5.7
Russet					
Maine	1.078	0.168	1.20	5.6	5.3
Washington [a]	1.084	0.167	1.20	5.6	5.3
Washington [b]	1.084	0.150	1.30	6.1	5.8
Washington	1.084	0.162	1.10	5.8	5.5
Idaho	1.085	0.164	1.05	5.7	5.4
Cobbler					
Minnesota	1.094	0.168	1.20	5.6	5.3
Av. Isotherm		0.164	1.18	5.7	5.4

[a] Precooking only.
[b] No precooking, no cooling.

The monolayer value, a_1, actually represents a moisture content on a moisture-free basis; hence this value has also been expressed on an "as-is" basis. The B.E.T. plot of the isotherm in Fig. 1 is shown in Fig. 2.

The data in Table 4 show, on the whole, that the calculated optimum moistures are slightly lower for the lower-specific-gravity varieties; this probably reflects the difference in starch content. The values range from 5.1 to 5.8% moisture (wet basis). However, considering the wide geographical distribution and the differences in starch and solids contents, all display a remarkable uniformity. Salwin gave a value of 5.46% for potato dice; this value is very close to the values calculated for the different flakes.

Cording *et al.* (1961) reported that flakes containing 5% moisture, made as previously described (Cording *et al.*, 1957), packed in air, and stored at 75°F, had a 6-month shelf-life.

To answer the questions of whether shelf-life can be extended by drying to a lower moisture content and what is a reasonable upper limit, a storage test was made. Flakes were made from Idaho Russets as described in the references cited above, air packed, and stored at 75°F. To establish a range, three moisture contents were selected: 4.0, 6.6, and 9.6%. These were periodically evaluated by 18 trained tasters.

Some of the significant results are given in Table 5. These data reveal: 1) drying to 4% gives shelf-life of only 1 month whereas flakes of 9.6% moisture had already deteriorated to unacceptability during the same period. However, although the 4% flakes deteriorated in one month, the 6.6% remained acceptable for 6 months. This gives us our moisture range: 5.0–6.6%. Within this range, flakes have a shelf-life of 6 months when air packed and stored at room temperature.

The B.E.T. theory predicts that 5.4% (wet basis) should be the optimum moisture content for Idaho Russet flakes. This value (5.4%) lies within the range experimentally determined. Furthermore, the B.E.T. theory predicts that overdrying should shorten shelf-life for flakes by removing the protective film which acts as a barrier against oxygen uptake. The flakes containing 4% moisture, which is 75% of the monolayer value as predicted, had only a 1-month shelf-life.

The storage data and the calculated monolayers ranging from 5.1 to 5.8% moisture for potato flakes well confirm the theory that the B.E.T. monolayer is a good first target for good storage stability (Salwin, 1963).

Table 5. Effect of moisture content on shelf life of potato flakes stored at 75°F.

Storage (months)	Acceptability (Moisture as is) 4.0%	6.6%	9.6%	Ranking [a]
1	A	A	U	4.0 and 6.6% significantly better than 9.6%, no difference between 4.0 and 6.6%.
2	U	A	U	6.6% significantly different and better than 4.0 and 9.6%.
3,4,5,6	U	A	U	

A = acceptable; U = unacceptable.
[a] Ranking Test: Simple ranking test; differences calculated at the 95% level of reliability.

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